Technical Memorandum 80271

(NASA-TM-80271) A CHANGE IN THE X-RAY SPECTRUM OF MK 421 (NASA) 14 p HC A02/MF A01 CSCL 03A
N79-23856
Unclas
G3/89 25918

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APRIL 1979

National Aeronautics and
Space Administration

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ABSTRACT

HEAO-1 experiment A-2 observations of the BL Lac object MK421 in May 1978 show a marked spectral change from the OSO-8 observations of May 1977 (Mushotzky et al. 1978). The source was not detected above 10 keV in May 1978. The 2-10 keV spectrum could be well fit by a power law of energy slope $2.2 \leq \alpha \leq 4.2$; thermal bremsstrahlung models with $T < 2 \times 10^{7}$ °K are also acceptable. There was no indication of any low energy turnover, so that the inferred column density $N_H < 7 \times 10^{21}$ at/cm^2. The total flux is consistent with an extrapolation of the UV data from IUE (Boksenberg et al. 1978), but the slope is not consistent with the UV slope. Possible models for the origin of the spectral transition are discussed.

Subject headings: BL Lacertae objects - X-rays:sources - X-rays:spectra

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I. INTRODUCTION

Many BL Lac objects have recently been confirmed to be sources of both hard and soft X-rays (Schwartz et al. 1979). Spectral studies of MK501, MK421 and PKS0548-322 (Mushotzky et al. 1978; Hearn, Marshall and Jernigen 1979; Riegler, Agrawal, and Mushotzky 1979) have demonstrated that these 3 objects exhibit 2-component X-ray spectra. The soft component dominates below 4 keV and is significantly steeper than the flat hard component.

MK421, in particular, has shown extremely variable X-ray emission with the 2-10 keV flux variable by more than a factor of 100 (Cooke et al. 1978; Mushotzky et al. 1978) over a timescale of years, and by a factor of $\sim$ 20 on a time scale of days (Ricketts, Cooke and Pounds 1976). The ¼ keV flux has been reported to be variable by a factor 3 over .8 days (Hearn et al. 1978).

In this Letter we report a radically different spectral episode than has been previously observed, and discuss a possible origin for the spectral and intensity variation in MK421.

II. OBSERVATIONS

Our data were obtained from a pointed observation of the HEAO-1 experiment A-2[+] from 0300-1200 UT on 28 May 1978. The HEAO A-2

[+]The A2 experiment on HEAO-1 is a collaborative effort led by E. Boldt of GSFC and G. Garmire of CIT, with collaborators at GSFC, CIT, JPL and UCB.

experiment has been described in detail by Rothschild et al. 1978. For

these observations we have used the data from the argon counter sensitive in the 2-20 keV band and the xenon counter sensitive in the 2-60 keV band. Both detectors have dual fields of view ($3^0 \times 3^0$ and $3^0 \times 1.5^0$) and are multiwire multi-layer proportional counters. Background for these observations was obtained from source-free regions of the sky observed close in time to the MK421 pointed observation. Analysis of these data was performed in the manner described by Serlemitsos et al. 1976.

III. RESULTS

The spectrum of MK421 (Fig. 1) could be well fit by either a power law or thermal bremsstrahlung from a optically thin gas. The power law fit of the form

$$\frac{dN}{dE} = A \; E^{-\alpha} \; \exp\,(-\,\sigma\, N_H) \;\; \mathrm{ph/cm^2\ sec\ keV}$$

gives A = .13, and α = 3.9 (+1.3, -.7) and $N_H < 7 \times 10^{21}$ at/cm^2 (all errors are 90% confidence combined errors). The absolute intensity could be uncertain by $\pm$ 20% due to aspect errors. The thermal model fit constrains the temperature to be less than 1.9 keV with $N_H < 6 \times 10^{21}$ at/cm^2. These limits on column density are similar to those derived by Mushotzky et al. 1978. No evidence is found for X-ray emission above 10 keV with upper limits of 5×10^{-5} ph/(cm^2 sec keV) out to 30 keV. The 2-6 keV flux is 2.56×10^{-11} erg/cm^2 sec and the 2-10 keV flux is 2.79×10^{-11} ergs/cm^2 sec, consistent with the HEAO-1 flux derived from scanning data in Nov 1977. At a distance of 180 Mpc (Ulrich et al. 1975) this indicates a 2-10 keV luminosity of 1.07×10^{44} ergs/sec. Similar results reported by Schwartz et al. 1979 confirm the intensity

variability of the total source intensity but do not possess energy resolution sufficient to address the spectral variability claimed here.

IV. DISCUSSION

We will compare the present result to previous observations in the light of a two-component model for BL Lac X-ray spectra. This representation of the data seems particularly applicable for MK421 since the present observations show the soft ($E < 4$ keV) spectrum to vary less than the hard ($E > 4$ keV) X-ray data.

Comparison of the present results with the OSO-8 results in May 1977, Fig. 2, shows that the hard component evident at that time has varied by at least an order of magnitude while the soft component has varied in intensity by $\sim$ 30%. The hard component in the OSO-8 spectrum taken with a 5^{o} FWHM collimator might be due to the inclusion in that observation of a different nearby source. However, the similarity of the OSO-8 result to HEAO-1 results for MK501 and PKS0548-322 (Mushotzky et al. 1978; Riegler et al. 1979), combined with the absence of any close source in the X-ray source catalogs or in HEAO-1 scanning data, argues against this possibility.

The detailed fit to the HEAO-1 data results in a slope significantly different than the $\alpha = 2.1^{+.4}_{-.3}$ photon index reported by Hearn et al. below 4 keV. Thus, in addition to intensity variability and the "disappearance" of the hard component, the soft spectrum has been observed to change its shape.

IUE observations 3 months earlier (Boksenberg et al. 1978) quote a photon index $\alpha = 2.2$ for a fit from $5 \times 10^{14} - 2.5 \times 10^{15}$ Hz. Extension

of this result would give a 2-10 keV X-ray flux of 2.6×10^{-11} ergs cm^2 sec, consistent with our total flux. However while the UV spectral index is consistent with the X-ray index of Hearn et al. it is not consistent with ours. Thus the X-ray points do not lie on a power law extrapolation of the optical and UV data and our results can rule out an extrapolation of the UV power law into the X-ray band.

Various authors have proposed that the optical UV spectrum is synchrotron in nature. For a synchrotron spectrum the "broken" part of the power law should have a slope roughly 1 greater than the lower frequency spectrum and for MK421 a radio index of $\alpha \sim .26$ is consistent with this hypothesis. At very high frequencies the synchrotron spectrum should become roughly exponential in nature. However, as exhibited in Fig. 3, the UV and the X-ray do not match up, making this simple explanation unlikely unless the source was $\sim$ 8 times brighter in the UV in May than in Feb. We note that the SAS-3 data (Fig. 3) are consistent with an extrapolation of the UV spectrum, but require MK421 to have been $\sim$ 5 times brighter in the UV in 1976 than in Feb 1978.

Another possible interpretation of the soft X-ray component would be emission from a cloud of hot gas at temperatures $T \lesssim 2 \times 10^{7\,o}$K. In order to account for the X-ray variability at ¼ keV this cloud would need to be less than $\sim 5 \times 10^{15}$ cm in size. The emission integral for this hot gas is $n_e^2 V \sim 5 \times 10^{67}$ which for $T \sim 5 \times 10^{6\,o}$K and spherical geometry would give $n_e \sim 10^{10}$ and a cooling time of roughly ½ day. This model could therefore account for the time variability as a cooling effect but would require continuous energy input to keep the gas hot. This

gas would have a mass of $\sim 4\ M_0$ and would have a pressure $\sim$ 2000 times that of an optical filament in a typical QSO or Seyfert. This might account for the absence of optical lines in BL Lac objects.

The high energy flux has been well modeled as being due to the synchrotron self-Compton mechanism (Margon, Jones and Wardle 1978; Schwartz et al. 1979). Its radius of less than 1.4 light years (Margon et al.) derived from radio data is consistent with our observed hard X-ray variability time scale of less than 1 year. The virtual disappearance of the hard component would argue for a change in the high frequency radio flux; a complete model test would require simultaneous radio data. In an SSC model one can get large flux variability in the X-ray unaccompanied by similar large changes in the optical or radio band if the source size is changing (Mushotzky et al. 1978). Thus we cannot predict whether or not the optical non-thermal component in MK421 would exhibit measurable variation during the 1977-1978 period.

Schwartz et al. have suggested that the situation in MK421 is reminiscent of the transition in Cyg X-1. Theoretical models of accretion onto massive black holes (Eardley et al. 1978) characterize the change from a soft-and-hard to a soft-only spectrum as a shift from a "two temperature" disk to a "standard" disk. The published theoretical spectra of Eardly et al. show an inflection point, characterizing the transition region between the soft and hard component, at $E \sim 1$ keV for a $10^3\ M_0$ blackhole. For the larger mass black holes necessary to provide the X-ray luminosity in MK421 ($M_{hole} > 10^5\ M_0$) this inflection point moves to energies less than 1 keV, inconsistent with the present data. However, this parameter is not well determined in these models and the rough

agreement in spectral shape is suggestive. The required accretion rates of $> 10^{24}$ g/sec are not unreasonable. The size of the disk $\gtrsim 2 \times 10^{11}$ cm is also consistent with the variability timescales. In this model the predicted UV and optical luminosities lie well below the observed values due to the curvature of the spectrum at very low energies, so that there is no inconsistency if the UV and optical emission are not dominated by the disk contribution.

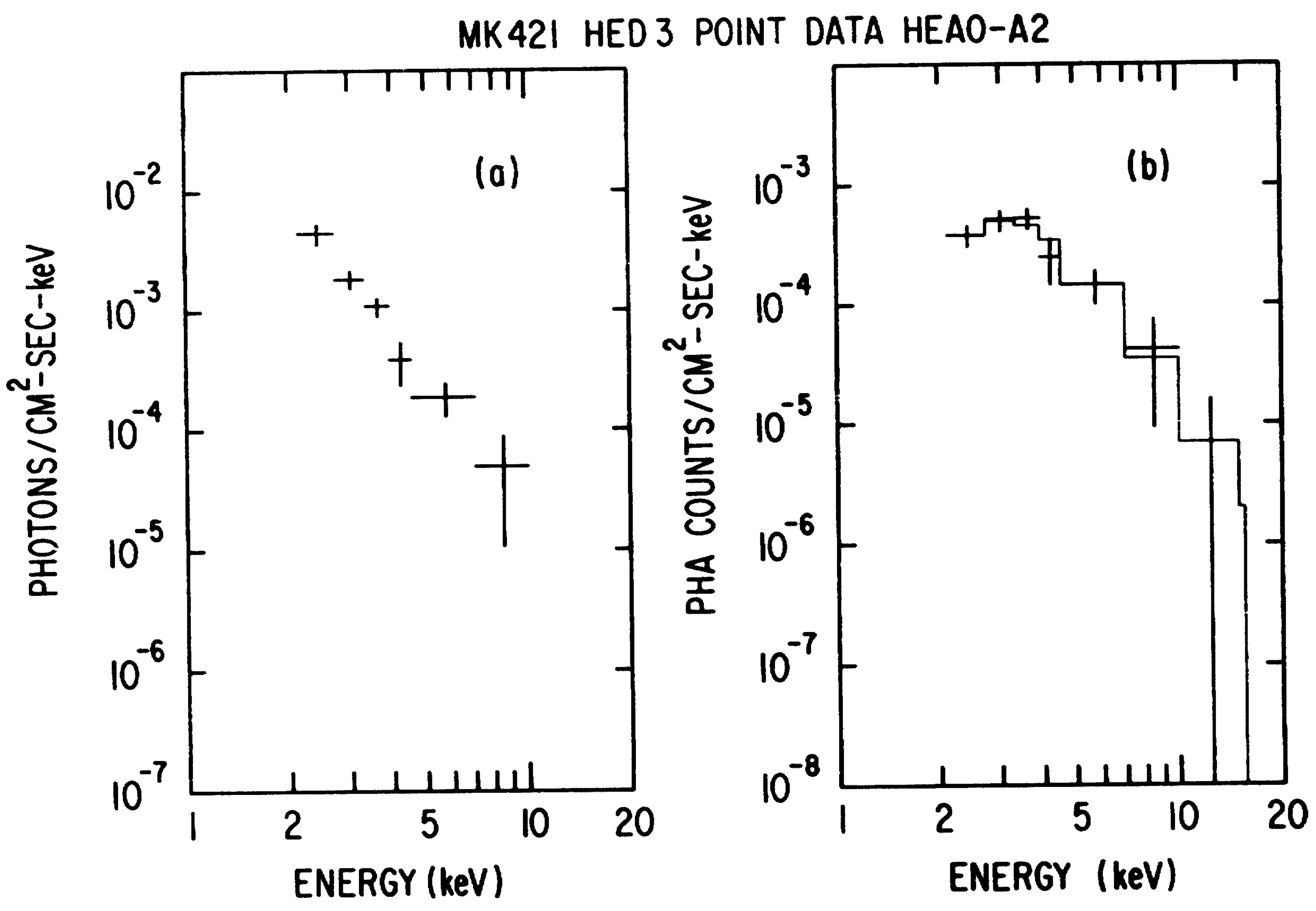
We wish to thank J. Swank, F. Marshall, S. Pravdo and R. Rothschild for their extensive help with the HEAO A-2 experiment.

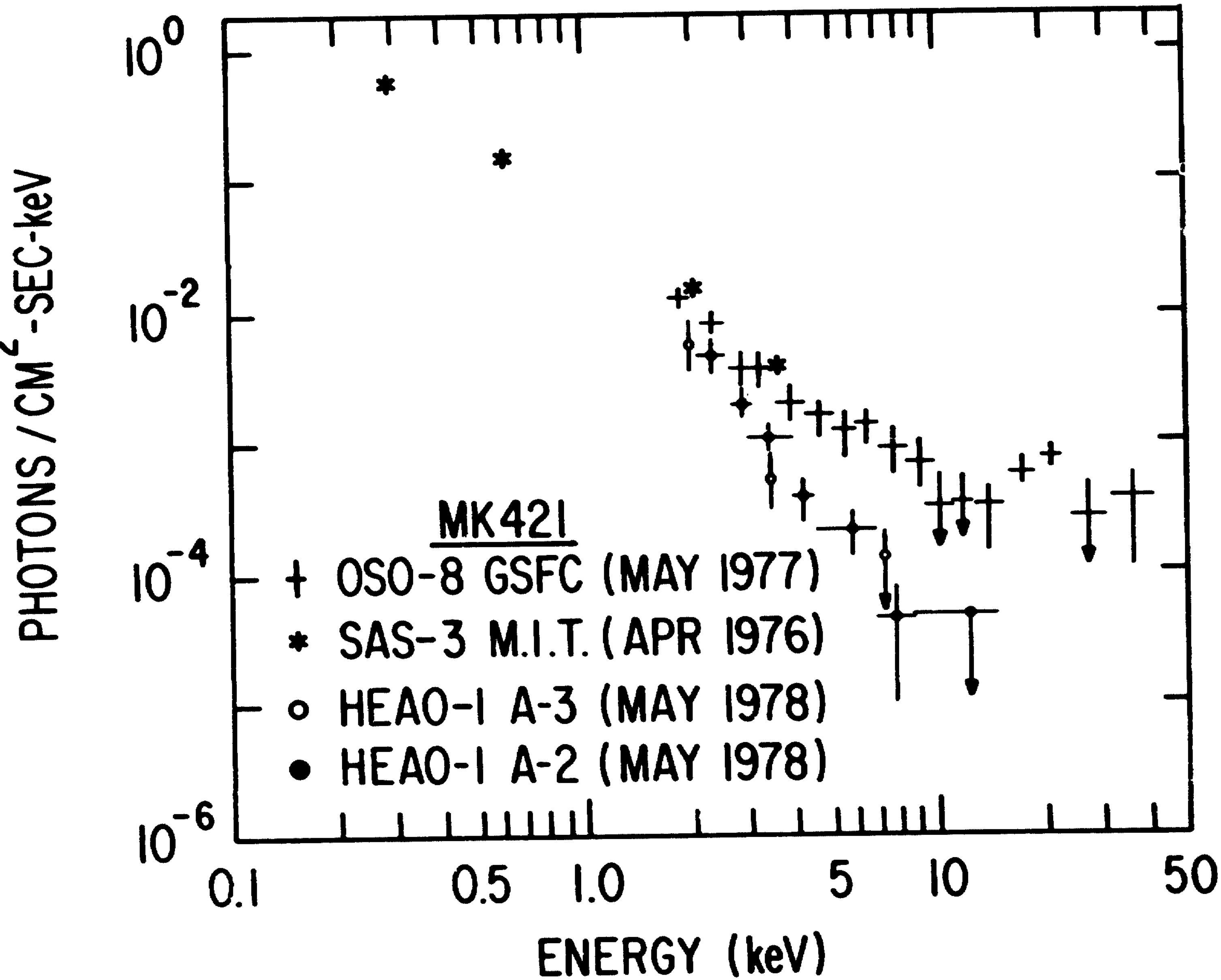
FIGURE CAPTIONS

Figure 1a - The photon spectrum of MK421 in units of photons/cm^2 sec keV.

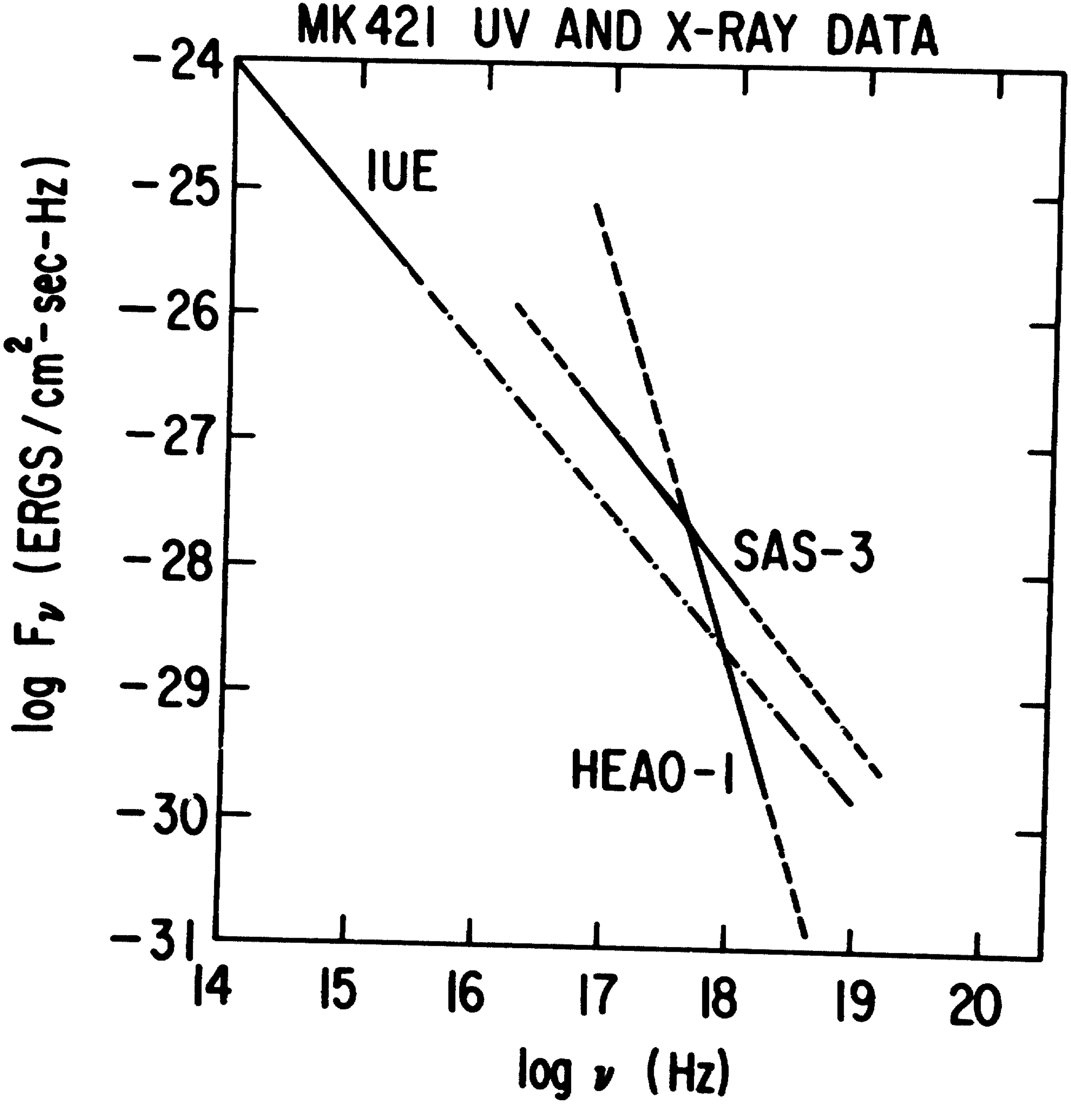
Figure 1b - The pulse height spectrum of MK421. The solid line indicates a power law of slope 3.8 convolved with the detector response.

Figure 2 - The X-ray spectrum of MK421 as reported in this work, Schwartz et al. (1979), Hearn et al. (1979), and Mushotzky et al. 1978. The SAS 3 and HEAO 1 A-3 points have had their energy widths removed for clarity.


MK421 HED 3 POINT DATA HEAO-A2
(a)
PHOTONS/CM^2-SEC-keV
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
1
2
5
10
20
ENERGY (keV)
(b)
PHA COUNTS/CM^2-SEC-keV
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
1
2
5
10
20
ENERGY (keV)



PHOTONS / CM^2-SEC-keV
10^0
10^{-2}
10^{-4}
10^{-6}
MK421
OSO-8 GSFC (MAY 1977)
SAS-3 M.I.T. (APR 1976)
HEAO-1 A-3 (MAY 1978)
HEAO-1 A-2 (MAY 1978)
0.1
0.5
1.0
5
10
50
ENERGY (keV)


MK421 UV AND X-RAY DATA
IUE
SAS-3
HEAO-1
-24
-25
-26
-27
-28
-29
-30
-31
14
15
16
17
18
19
20
log F_ν (ERGS / cm^2-sec-Hz)
log ν (Hz)

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